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The Geometry Prediction of Back-bead in Arc Welding

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아크 용접에서 이면비드의 기하학적 예측

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Abstract

This research was done on the basis of assumption that there is a relationship between welding parameters and geometry of the back-bead being a gap in arc welding. Multiple regression analysis was used as method for predicting the geometry of the back-bead. The analysis data and the verification data were used for the formation of multiple regression analysis. The method was used to perform the prediction of the back-bead.

Key Words : Artificial neural network(인공 지능 기법), Multiple regression analysis(다중 회구 분석), Geometry of back-bead(이면 비드의 형상), Arc welding(아아크 용접)

1. Introduction

In gas metal arc welding, the weld quality is greatly affected by the welding parameters. Especially, the welding parameters are closely related to the geometry of the back-bead. Repeated experiments are needed in order to determine the optimal welding conditions in the welding parameters. Also, the optimal welding conditions are determined by combined factors such as the type of base metal, the welding process, and the geometry of the welded parts. Therefore, an immense amount of data is needed in order to obtain optimal welding conditions. In reality, as this amount of experimentation is impossible, a research method which can predict the geometry of the back-bead is necessary.

Investigation into the relationship between the welding parameters and bead geometry began in the mid 1900's, and regression analysis in welding geometry was applied by Raveendra and Parmar1in 1987. Chandel[2] suggested the correlation between the welding process parameters

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and bead geometry in bead-on-plate of gas metal arc welding. He confirmed that the arc current was a major parameter in determining the bead geometry. Yang, *et al.*[3] used the linear and curvilinear models to calculate the bead height from the welding process parameters in the regression equation. Also, Il-Soo Kim, *et al.*[4] empirically confirmed Yang's linear, curvilinear methodology. However, there has not been any research in real welding where a gap in butt welding has been considered.

Therefore, the objective of this study is to obtain the desired weld bead in real welding by predicting the geometry of the back-bead using welding parameters in gas metal arc welding. The multiple regression analysis was used in the research. First, an experiment system was configured to predict the back-bead geometry. And the prediction method was compared and analyzed.

2. Experiment

2.1 System configuration

The system configuration consists of the 3-axis table system, welding machine and measuring system. The CO_2 arc welding machine was used as a welding power source and CO_2 shielding gas was used. A laser vision sensor was used to measure the geometry of back-bead. The flow rate of the shielding gas was 15 l/min and the CTWD(contact tip to workpiece distance) was fixed to 15mm. The feed wire which was used had a diameter of 1.2mm. The system configuration of the experiment is shown in Fig. 1. and Fig. 2.

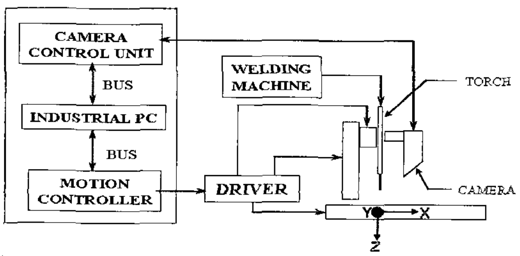

Fig. 1 System configuration for prediction of back-bead

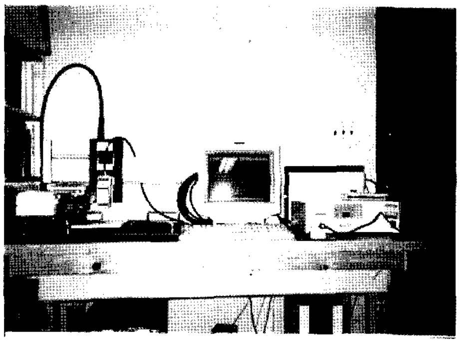

Fig. 2 System configuration for experiment

2.2 Image processing to obtain experimental data

It is necessary to measure data in order to produce the quantitative width and depth of the back-bead. The laser stripe, which is the shape of the welding bead, is obtained through the laser vision sensor. This stripe is composed of 256 points. In order to measure the width and depth of the back-bead, these points were expressed in lines or curves. Generally, a parametric form is often used as a plain curve. The image processing method was performed as follows. The segment splitting method[5]was used to calculate the straight line which is most approximated to the laser stripe. This method is performed by finding a break point from the end points. Fig. 3 shows the segment splitting method which was used to express the outline. Here, the first edge point B_0 and the final edge point B_6 are connected in a straight line. The point which is farthest from this line is found and labeled B_3. This method is continuously performed to find the edge points of B_1 and B_5, the farthest edge point B_2 from B_1 and B_3, and the farthest edge point B_4 from B_3 and B_5. The perpendicular distance is calculated from the line in which the two edge points that were found through approximation were connected. Also, if the line distance between each point was smaller than the threshold, the program would be stopped. If not, the program would be repeated. In this study, the threshold(perpendicular distance) was 2 mm. The program was continuously performed until a maximum of 17 edge points were generated. A laser vision sensor with a resolution of 0.05mm was used

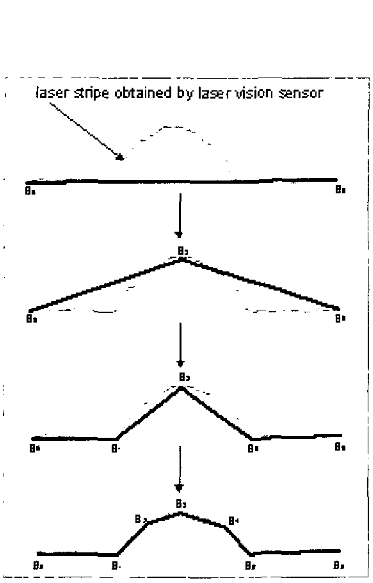

Fig. 3 Segment splitting method for a stripe representation

Fig. 4 Welded bead in front view for stripe representation

for the accurate measurement of the back bead.

2.3 Experimental method

In the experiment, SS41 mild steel was used as the specimen(180(width)×100mm(length)×6mm(thickness)) (Fig. 4). Butt welding was performed on the specimen and the welding parameters and welding conditions used in the experiment are as shown in Table 1.

The conditions in Table 1 were combined and 96 experiments were performed three times each. The mean width and mean depth of the back-bead were obtained by the average value of three repetitions per each experiments condition. Of the 100mm welding direction of the welded specimen, the widths and depths of the back-bead

Table 1 Welding variables and conditions[6]

variables	units	conditions
gap	mm	1.2, 1.3, 1.4, 1.5
current	ampere	200, 210, 220, 230
voltage	volt	24, 25
speed	mms^{-1}	4, 5, 6

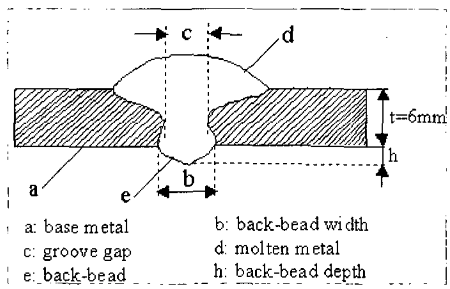

Fig. 5 Schematic diagram of width and depth of back-bead

in the welding line of 80mm were obtained by the vision sensor excluding each 10mm of the first and final in welded part are not enough to use as experimental data.

The mean width and mean depth of the specimens' back-bead were used as data for the prediction of the back-bead. The schematic diagram of the width and depth of the back-bead is shown in Fig. 5. The width and depth of the back-bead under gas metal arc welding showed different results for each experiment in the same location and the same welding conditions. Therefore, it is important to perform image processing on the measured profile through the vision sensor in order to calculate the mean width and mean depth of the back-bead. The length of the welding part made by blow hole or pitting were excluded for the objective prediction of the width and depth of the back-bead. The vision sensor used in calculating the profile had an output power of 40mmW and was equipped with laser diode with a wavelength of 680nm and band pass filter with a bandwidth of 10nm. Also, 40 profiles can be done per seconds. Each profile has 256 edge points.

3. Multiple regression analysis

In this study, the relation among the gap, arc voltage, welding current, welding speed and the width and depth of the back-bead was examined. In order to predict the width and depth of the back-bead using these relations, the statistical method of multiple regression analysis was used, and a regression model was made for the prediction of the bead geometry. The independent parameters in the multiple regression analysis were made by arc voltage, welding current, welding speed and gap. The dependent parameters were made by width and depth of back-bead.

A regression analysis of 48 experimental conditions having a gap of 1.2mm and 1.5mm was considered. The 96 experimental conditions in Table 1 were experimented. The propriety of a regression model in the verification level was investigated using 8 random conditions when the gap is 1.3mm and 1.4mm. The software used in regression analysis of this study was a commercial statistical program SPSS.

4. Results and discussion

The welding parameters and the width and depth of the back-bead geometry are thought to have a complicated correlation. The results of analyzing the correlation are shown in Table 2.

As shown in Table 2, the width and depth of the back-bead show a linear pattern. Therefore, the regression analysis of the input parameters is expressed in linear equations. They are shown in equations (1) and (2).

$$WIDTH=7.006+0.303*G+0.850*C+0.291*V-2.730*S \quad (1)$$

$$DEPTH=3.417+0.317*G+0.529*C+0.147*V-1.330*S \quad (2)$$

Where, WIDTH: width of back-bead(mm), DEPTH: depth of back-bead(mm), G: gap of between specimens (mm), C: welding current(ampere), V: arc voltage(voltage), S: welding speed(mm/sec)

In order to guarantee the reliability of the regression analysis, the coefficients of the regression model were estimated at a significance level of 0.05. The parameters in which the probability value(p-value) of each coefficient's t-statistical value was above 0.05 were excluded, and the adjusted coefficients were found. The probability values of the coefficients of the regression model determined through the stepwise method are shown in Table 3.

A linear regression model was predicted from the data used in the analysis. The results of the measured values and predicted values were compared, and the width and depth of the back-bead are shown in Fig. 6 and Fig. 7. A linear regression model was predicted from the data used in the analysis. The results of the measured values and predicted values were compared, and the width and depth of the back-bead are shown in Fig. 6 and Fig. 7.

The analysis data and verification data are shown together in Fig. 6 and Fig. 7. In the case of the width of the back-bead, the adjusted coefficient is 0.953, and the standard error of the estimate is 0.217(Fig. 6). Because the adjusted coefficient shows a value close to 1(100%), the input parameters greatly affect the output which is the prediction of the back-bead, and it can be seen that accurate back-bead prediction is possible through

Table 2 Correlation coefficient between welding parameters and the size of the back-bead

	gap	current	voltage	speed	width	depth
gap	1					
current	0.836	1				
voltage	0.783	-0.037	1			
speed	-0.890	0.018	0.014	1		
width	0.879	0.812	0.765	-0.932	1	
depth	0.876	0.858	0.751	-0.887	0.880	1

Table 3 Significance level of regression model coefficient

	constant	gap	current	voltage	speed
P-value of width	0.013	0.008	0.011	0.032	0.003
P-value of depth	0.019	0.016	0.009	0.023	0.017

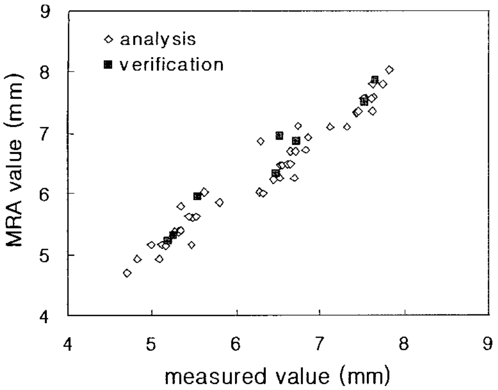

Fig. 6 Comparison of back-bead width between analysis data and verification data(measured values and multiple regression analysis(MRA) values)

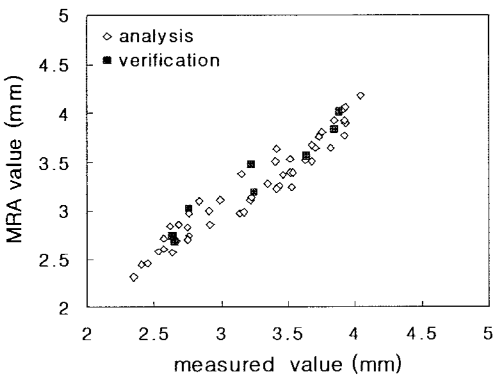

Fig. 7 Comparison of back-bead depth between analysis data and verification data(measured values and multiple regression analysis(MRA) values)

the model. The calculated error in the analysis and at the verification stage is as follows. The error at the analysis stage when using all 48 data used in the regression model is 2.44%, and the error at the verification stage when applying 8 new data is 2.94%. In the case of depth of the back-bead, the adjusted coefficient of the model is 0.924 and the standard of the estimate is 0.1393(Fig. 7). Also, the calculated error at the analysis and the verification stages is as follows. The error at the analysis stage when using all 48 data used in the regression model is 3.48%, and the error at the verification stage when applying 8 new data is 3.68%. It is shown that the

Table 4 Comparison of prediction errors

		multiple regression analysis
width of back-bead	adjusted R^2	0.953
	standard error of the estimate	0.217
	error for analysis or training(%)	2.44
	error for verification or test(%)	2.94
depth of back-bead	adjusted R^2	0.924
	standard error of the estimate	0.1393
	error for analysis or training(%)	3.48
	error for verification or test(%)	3.68

amount of adjusted coefficients of width and depth of the back-bead are over 90%. When the measured values and predicted values of width and depth of the back-bead are compared, prediction errors of both analysis and verification stage are within 4%. The results are shown in Table 4. The prediction comparisons of back- bead are shown in Table 4.

The prediction error for width of back-bead is smaller than that of depth of back-bead in method. This is thought to be because depth of back-bead is formed more irregularly than width due to the complex weld pool fluctuation.

5. Conclusions

This study was performed based on assumption that there would be a correlation between welding parameters and geometry of back-bead in gas metal arc welding. The multiple regression analysis is used as prediction method of back-bead geometry. The following conclusions are shown.

(1) There was partially a linear relationship between welding parameters and geometry of back-bead under optimal welding conditions.
(2) The width and depth of back-bead were represented as linear equations of the multiple regression analysis.
(3) The welding speed was the most important factor in the geometry of back-bead, followed by welding current, gap, and arc voltage.

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